

Government and Academia Partnership to Test and Evaluate Air Traffic Control Decision Support Software

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In the current air transportation system, decision support tools aid air traffic controllers in monitoring air traffic to maintain minimum separation standards between aircraft. These automated systems provide this service by predicting aircraft flight paths (trajectories) to foretell potential conflicts. The User Request Evaluation Tool (URET), developed by MITRE Corporation's Center for Advanced Aviation System Development, is an example of a decision support tool currently in operational use. The Federal Aviation Administration (FAA) has developed a new air traffic control system to replace URET. This system is called ERAM, for En Route Automation Modernization, and is being developed by the Lockheed Martin Corporation. After the Factory Acceptance Test Run for Record, a study was conducted by the Conflict Probe Assessment Team in support of the testing and evaluation of ERAM's trajectory prediction accuracy and strategic conflict probe. This article describes the partnership between the FAA and Rowan University established to develop visualization tools that aid the analysts evaluating the Run for Record test data. In addition, features of these visualization tools, how they were instituted during the study, and collaboration success stories are presented.

Key words: Aircraft trajectory; collaboration; conflict prediction; ERAM; Federal Aviation Administration; partnering; Rowan University; technology transfer; visualization.

The test and evaluation (T&E) process is the key to ensuring that a system is reliable, maintainable, and safe. It is the Federal Aviation Administration (FAA)'s mission to maintain a safe and efficient airspace system; hence the FAA is continuously exploring ways to improve their T&E abilities. The William J. Hughes Technical Center (Technical Center) in Atlantic City, New Jersey, is the lead test and evaluation facility of the FAA. The Technical Center has always valued partnerships that help improve the challenges of T&E. The Technical Center has embarked on collaborations with other international organizations through Action Plan 16 with EUROCONTROL, intergovernmental agencies through the Joint Development and Planning Office and Next Generation Air Traffic System (NextGen),

industry through a Collaborative Research Development Agreement (CRDA) with the Boeing Company developing the Aircraft Intent Description Language, and academia through the FAA/NASA Joint University Program. These collaborations have been proven to be vital in enhancing the T&E process.

Introduction

The FAA has developed a new Air Traffic Control (ATC) system to replace the existing host computer system in the en route domain. This system is called ERAM, for En Route Automation Modernization, and is being developed by the Lockheed Martin Corporation (LM). One primary component of ERAM is the Decision Support Tool (DST), which assists air traffic controllers in separating air traffic. Two key functions of ERAM's DST are the prediction of the future flight paths of the aircraft and the prediction of future conflicts between two aircraft or between an aircraft and a special use airspace. The

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Factory Acceptance Test (FAT) was successfully performed by LM in September 2007. After the FAT Run for Record (RFR), a study was conducted in support of the testing and evaluation of these two key functions (Paglione et al. 2008a). This study was conducted by the Conflict Probe Assessment Team (CPAT) in the Simulation and Analysis Team (AJP-661) at the Technical Center.

To properly test ERAM, we needed a large amount of data to analyze, thus the system outputs an ample amount of air traffic data. Visualization tools create visual overviews of the large amounts of abstract data that usually are stored in various database tables or files. With the involved task of analyzing the data, a need for visualization tools with which to easily interface the data was realized. Development of visualization tools is not a skill set that CPAT possessed; therefore, CPAT partnered with Rowan University's Software Engineering, Graphics, and Visualization Research Group (SEGV). Through this collaboration SEGV developed visualization tools to aid the analysts in evaluating the ERAM RFR test data in the newly established FAA/Rowan Air Transportation Research Laboratory (FRATR Lab). The FRATR Lab, located in the Department of Computer Science at Rowan University, is where SEGV was tasked to develop the visualization tools. The partnership proved to be a successful formula in achieving the goals of testing ERAM. Furthermore, using Rowan University was essential during this study because it allowed the analysts to focus primarily on data analysis and generation of test and evaluation reports, thus expediting the analysis and lessening the workload.

This article details the tools and how they were used in the testing and evaluation of ERAM, and the background of how the partnership between the FAA and Rowan University was established, its history, and its successes. Furthermore, we present descriptive illustrations of the visualization tools and application examples of their use.

ERAM trajectory and conflict prediction accuracy study

In 1996, the FAA established the CPAT at the Technical Center to evaluate the accuracy of the conflict probes in DSTs. Since its creation CPAT has measured the conflict prediction accuracy of URET (Cale et al. 1999), and measured the trajectory modeling accuracy of both URET and CTAS (Cale et al. 1999; Paglione et al. 1999). In 2004, the ERAM Test Group formed the Automatic Metrics Test Working Group. The group, led by CPAT, established a set of metrics to measure the performance of key functions of ERAM during developmental and oper-

ational testing (Paglione et al. 2006b). In 2007, ERAM was accepted by the FAA, having passed the performance requirements during the FAT RFR.

A follow-up study was performed by CPAT after the RFR. The study involved analyzing the results of FAT RFR Run 4, which dealt with the trajectory prediction accuracy implemented in ERAM's flight data processing, and Run 5, which involved the strategic conflict prediction accuracy implemented in ERAM's conflict probe tool (Paglione et al. 2008a). The tools that computed trajectory accuracy metrics for Run 4 were developed by CPAT, and the tools to evaluate the Run 5 data were developed by LM; however, CPAT has developed its own set of tools to measure the accuracy of strategic conflict predictions that have been used by CPAT in other tasks. A statistical approach was used to decide whether there was significant degradation in ERAM when compared with the legacy URET system. The purpose of the study was to further inspect the performance of ERAM, investigate areas where ERAM did indeed degrade from the legacy system, and provide an overview of the results to the FAA.

FAA/Rowan University collaboration

At the end of the fall 2004 semester, CPAT teamed with the SEGV Research Group established in the Department of Computer Science at Rowan University. Under a CRDA, the FAA provided, as government furnished equipment, desktop personal computers and Linux servers, and Rowan University established the FRATR Lab. The equipment matches the characteristics of the computers on which the software would finally be installed to accommodate easier deployment.

Figure 1 displays the overall structure of the partnership. The SEGV director negotiates with the FAA the details of the project(s) prior to their introduction into the classroom and coordinates the roles of the graduate and undergraduate students based on the scope and goals of each project. Being the liaison between the FAA and SEGV, the graduate students play roles on both sides: On the FAA side they schedule meetings and elicit new requirements from the users based on the FAA needs, and on the SEGV side they contribute by sharing the management of the projects and the mentoring of the undergraduate students participating in the projects. When they become very well accustomed to the projects' details, the graduate students play the role of the customer, thus relieving part of the workload of FAA managers. The graduate students perform installations and maintenance, and assure the smooth transition of the projects' versions from one undergraduate team to another.

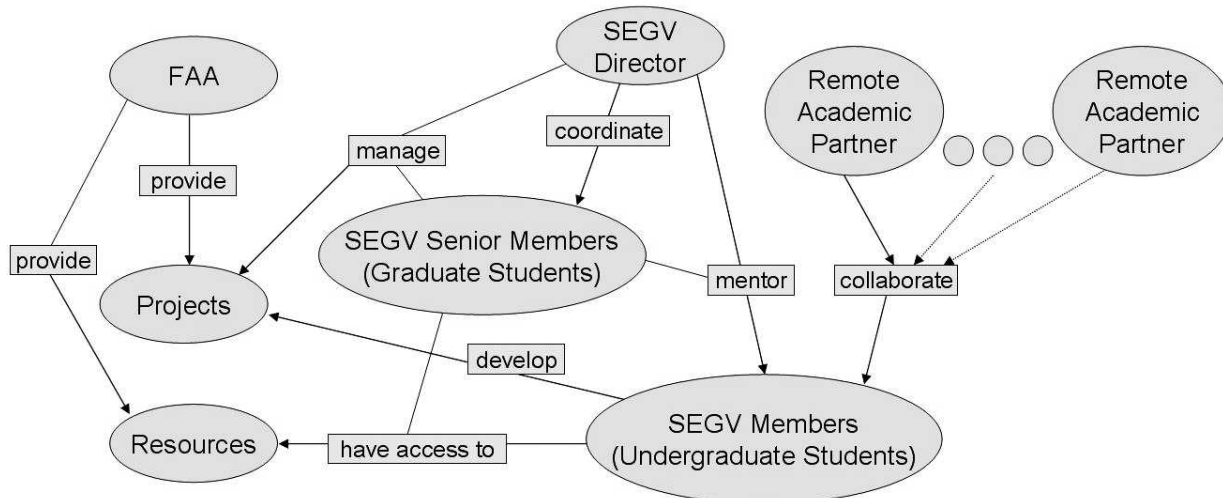


Figure 1. Overall partnership structure.

The partnership structure is flexible to allow easy addition of other academic partners. During the spring 2008 semester, we added Fairfield University students to our collaboration. Twenty students from both universities worked together in adding new functionality to existing FAA tools.

Visualization tools for testing and evaluation

A vast amount of data is generated when testing air traffic decision support software. During the T&E process, normally, data reduction and analysis (DR&A) tools are used to process the data and determine whether the software's (system's) performance is acceptable. Assuming the input data into the tools are correct, and the tools are implemented properly, the software's performance will be derived correctly; otherwise the results will be erroneous. In an attempt to prevent this case of "garbage in, garbage out," visualization tools can aid T&E analysts in validating the data. Information visualization is the visual representation of abstract data to help the user understand the data more effectively (Tufte 2001). This section presents two visualization tools that have been used in recent T&E procedures.

Trajectory graphical user interface

As previously mentioned, DSTs are used to assist air traffic controllers in the separation of air traffic. DSTs predict aircraft flight paths (trajectories) using the Trajectory Predictor and foretell potential conflicts using the Conflict Probe (CP). A trajectory is a four dimensional (latitude, longitude, altitude, and time) prediction of an aircraft's flight path. The accuracy (i.e., how close to the actual flight path's time and

proximity) of trajectories generated by DSTs determine their overall performance; hence the accuracy of trajectories is the subject of the T&E process. The performance accuracy of trajectories is quantified by comparing the trajectories to the actual flight paths they predict and computing a set of error metrics (Paglione and Oaks 2007). Various algorithms and relational databases have been developed to investigate and calculate the error metrics of trajectory prediction.

Trajectory Graphical User Interface (Trajectory-GUI) is a visualization tool developed in the FRATR lab, currently used by the CPAT to evaluate the accuracy of predicted trajectories (Santiago et al. 2005). Previously, analysts would have to manually collect the trajectory accuracy results from the database, organize it for analysis, and then finally analyze the results. Using TrajectoryGUI, the process of validating the T&E metrics results are expedited because it allows the analyst to focus on evaluating the data only. Trajectory-GUI provides a graphical user interface to easily choose the data to visualize and automatically formats the data. An analyst can use TrajectoryGUI to package the trajectory accuracy results and illustrate reasons for inaccuracies.

TrajectoryGUI was entirely developed through the collaboration between the FAA and SEGV. Trajectory-GUI allows the analyst to create two-dimensional plots of flight track and trajectory error data fields, such as X-Y (latitude vs. longitude) and T-Z (time vs. altitude). Each plot can contain multiple actual flight paths, and each flight path can contain multiple trajectory paths. Illustrations of TrajectoryGUI and how it was used in support of the T&E of ERAM will be presented in the section titled "Evaluation of trajectory prediction accuracy."

Flight graphical user interface

Conflict probes provide air traffic controllers with predictions of conflicts (i.e., loss of minimum separation between aircraft, normally five nautical miles) within a parametric time (e.g., 20 minutes) into the future. Accuracy T&E requires detailed analysis of the conflict probe's predictions. The ultimate goal is to improve the accuracy of these predictions. The accuracy of a conflict probe is measured by a set of metrics involving the accuracy and timeliness of predicting conflicts and the reduction of falsely predicted conflicts.

Flight Graphical User Interface (FlightGUI) is a visualization tool developed in the FRATR lab, currently used by the CPAT to test the conflict prediction performance results of CPs (Santiago et al. 2006). As is the case with TrajectoryGUI, FlightGUI allows the analysts to focus primarily on the validation of a CP's metrics results, and not the querying or managing of the data. Additionally, the visualization provides a display in which the analyst can gain a better understanding and overview of the results, in comparison to the analyst having to perform a collection of difficult database queries, and standard spreadsheet data calculations and analyses.

FlightGUI animates the flight paths of aircraft by displaying their spatial-time relationship to each other during an encounter of a flight pair. An encounter is a precursor event to a conflict where a flight pair loses minimum separation that is greater than a conflict (e.g., 40 nautical miles) and is only for analysis purposes when testing conflict probes. FlightGUI indicates when a conflict occurs by encircling the conflicting flights (i.e., nonadherence to minimum separation standards), which aids the analyst in noticing the conflict; then the analyst studies its characteristics by analyzing the information about the aircraft in tabular form. This allows the analyst to study whether the conflict has been accurately predicted. Furthermore, the analyst has the ability to animate the encounters (nonconflict events) to study the characteristics of flight pairs that were on the edge of becoming a conflict and whether the CP falsely predicted this nonconflict event as an imminent conflict. Examples of how FlightGUI was used in the study reviewing the results of the Flight Data Processing/Conflict Probe Tool ERAM Run 4 and 5 appear in the next section.

Applications in testing and evaluation

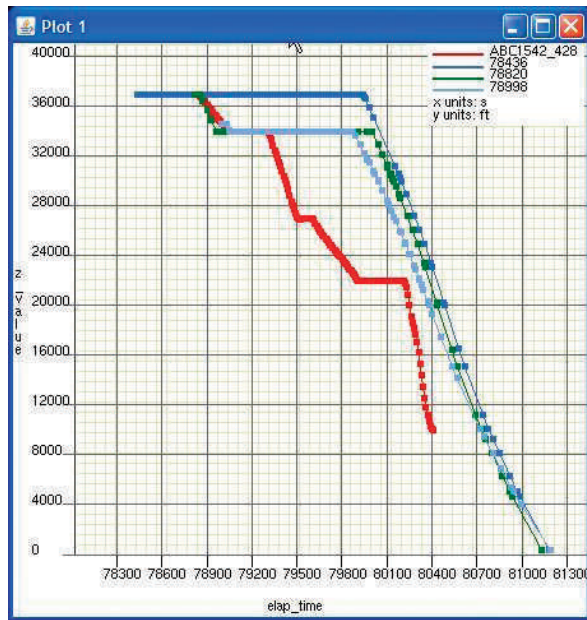
In September 2007, the FAA successfully implemented the ERAM formal RFR and accepted the new system. Following the RFR, CPAT was tasked to perform a follow-up study examining the RFR

trajectory and conflict probe accuracy results. During this study CPAT utilized its collaborative partnership with Rowan University, which had already been established, to bolster its capabilities, and inexpensively increase manpower and laboratory resources. The major purpose of the study was to examine the test results and provide an overview of the performances. This section describes how two academically developed visualization tools were used in the T&E of ERAM's DST.

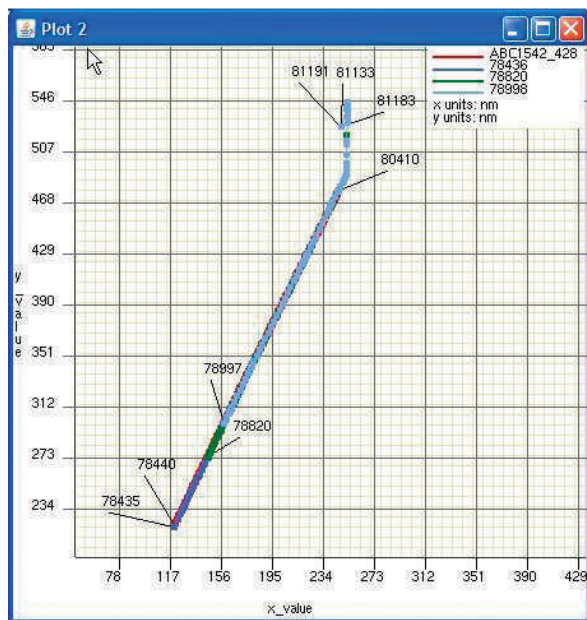
Evaluation of trajectory prediction accuracy

The first analysis of the study was to investigate the vertical accuracy of ERAM trajectories. Two main requirements of the ERAM trajectory modeler were to be at least as accurate as URET (a) during level phases of flight, as well as (b) in the transitioning phases of flight. The performance of ERAM compared to URET is quantified by applying statistical analysis to a set of accuracy metrics. By investigating outliers on a flight by flight level, the analyst has the ability to not only uncover errors in the ERAM system itself but also in the set of offline support tools that process the test results and calculate the error metrics for postanalysis. This section details application examples of how TrajectoryGUI aided test analysts in evaluating the trajectory prediction accuracy of ERAM, as well as validating the test error metrics.

In this example, the aircraft is an Airbus A320 flying from Orlando International Airport, Orlando, Florida, to Washington Dulles International Airport, Washington, D.C. (MOC). The actual flight path and trajectories generated by ERAM are shown in *Figure 2*. *Figure 2a* depicts the vertical profile of the flight while in the Washington D.C. Air Route Traffic Control Center. *Figure 2b* illustrates the horizontal profile as it makes its approach to the MOC airport. For both plots, the red path is the actual flight path and the series of other paths are the trajectories. Each trajectory is identified by its trajectory build time, which is the time (seconds in the day) in the day the trajectory was generated. For this aircraft, ABC142_428, there are three trajectories: 78436s (dark blue), 78820s (green), and 78998s (light blue). The aircraft is flying at its cruise altitude of Flight Level (FL) 370, and at time 78840s the aircraft begins its arrival descent. The active trajectory when it begins its descent is 78820s, and as shown in *Figure 2a*, the trajectory correctly predicts the descent. Next, the aircraft descends to FL340 as it was instructed to do by the ATC, and remains level until time 79310s. When the aircraft begins to descend from FL340, neither the active trajectory, nor any previous trajectories, correctly predict this event. The trajectory predicted had the



a



b

Figure 2. TrajectoryGUI. (a) Vertical and (b) horizontal profile of flight examined during the ERAM RFR study.

aircraft continually descending from FL340 to touch down at the MOC airport, when in fact the aircraft flew in a series of two additional level off periods, and when regaining descent clearance, descended much faster than what was predicted. This case resulted in an average vertical error of $-5,608$ feet, meaning the actual flight path was below the trajectory predictions. This was indeed an outlier and was a candidate for reporting to ERAM developers and reporting in the

study. In contrast, the horizontal profile of this aircraft, shown in Figure 2b, clearly resembles an accurate prediction because the visualization represents overlapping paths, indicating that ERAM correctly predicted the horizontal path of the flight.

Utilizing the user-friendliness of TrajectoryGUI, the analyst was able to gather this information by a series of simple user interface selections from the visualization tool. The analysts were able to use TrajectoryGUI to investigate cases like the aforementioned, and many others, during the ERAM RFR study at a minimal cost of time and effort. The alternative is to use different methods of extracting the data, plotting, and performing the calculations; TrajectoryGUI achieves these features all in one system.

Evaluation of strategic conflict probe performance

The second analysis of the study was to evaluate the performance of the strategic conflict probe. Six requirements involving the accuracy of the strategic conflict probe were applied, three to aircraft-to-aircraft events and the same three to aircraft-to-airspace events. These requirements were used to ensure that ERAM (a) predicted conflicts in a timely fashion (i.e., predict conflict approximately 5 minutes before occurring), (b) minimized the number of missed conflict alerts (conflict occurs, but is not predicted), and (c) reduced the number of falsely predicted conflict alerts (conflict is predicted, but does not occur) for both types of events. This section introduces application examples of how FlightGUI was used to evaluate ERAM as a DST for ATCs, and validate the RFR test results.

It is important to have correctly functioning support tools if you are to correctly evaluate the performance of any system. During the ERAM RFR study, several discrepancies were found in support tools developed to calculate the performance of ERAM's strategic conflict probe. FlightGUI, in many ways, was a key factor in discovering these discrepancies. Although there were several discrepancies, details of one key discrepancy are presented in the next paragraph.

In review, a strategic CP predicts potential conflicts sometime in the future (i.e., 20 minutes), and a conflict is the loss of minimum separation by an aircraft pair. Furthermore, if an aircraft within a conflict is not adhering (i.e., adherence age less than 13 minutes) to its known ATC clearance, the conflict is discarded and not considered in the measurement of a strategic CP's performance. Adherence age is the amount of time (normally in seconds) the aircraft is not following its known clearance and has been studied by CPAT in previous work (Oaks 2005).

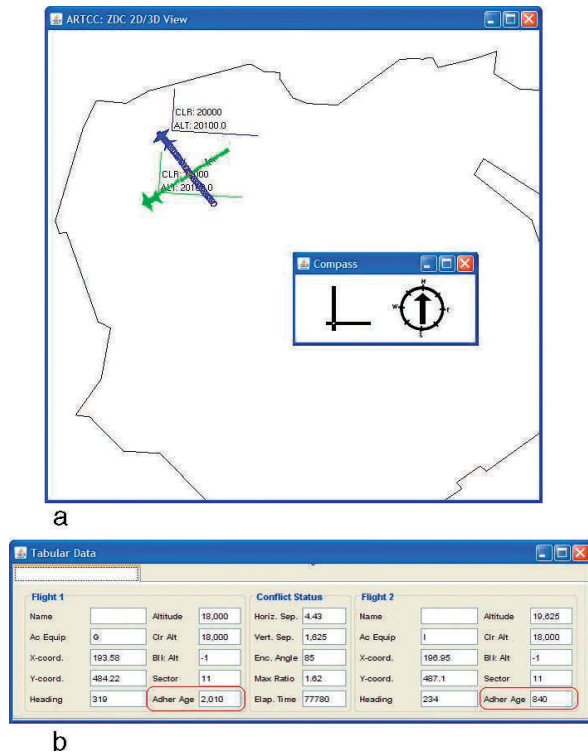


Figure 3. FlightGUI. Flight path of erroneously discarded conflict due to out of adherence. (a) The Visualization Window details the flight paths of this conflict. (b) Tabular data window details the characteristic of the conflict at the start of the conflict.

Through the use of FlightGUI during the study, the analyst was able to interface the track data for offline animation of a conflict, as well as interface the database storing the adherence values for the aircraft. Figure 3 illustrates a case where a conflict occurred, and the adherence ages for both aircraft were greater than 13 minutes (see red callout in tabular data window). This conflict was not correctly accounted for in the ERAM RFR test results because LM's support tool considered the aircraft to be out of adherence. The use of FlightGUI confirmed this discrepancy and helped find six similar cases. This had large ramifications for the T&E of ERAM during the RFR, and, in fact, called for the change of passing the aircraft-to-aircraft missed conflict alert requirement to failure because conflicts that had no prediction were erroneously discarded in the data reduction and analysis process. This is just one application example of how FlightGUI aided in the ERAM RFR study; others are presented in the study itself (Paglione et al. 2008a).

Success Stories

The collaboration allowed Rowan University to be selected as the winner of the 2008 FLC Northeast

Regional Industry/Non-Federal Government/University Award. This award recognizes an American-owned company, a nonfederal government entity, or a university within the region that has made outstanding efforts to promote the transfer of federal technology during the previous year. Since the inception of the collaboration, 35 undergraduate members of the SEGV research group have taken advantage of the partnership with the FAA and have participated in projects in the FRATR lab. All undergraduate students have been recognized with certificates of appreciation during specially arranged presentation sessions at the end of the corresponding semesters. The students have also presented their work and received recognition on campus, during Rowan's Science, Technology, Education, and Mathematics Student Research Symposium.

The experience accumulated during the development of the products and the certificates of appreciation the undergraduate students received helped the majority of them secure jobs in the aviation industry and similar industries. In fact, at least 11 of the 35 undergraduate students who participated in the collaboration received offers of employment from FAA contractors. In addition, the experiences gained by working on the projects propelled some students into graduate school. Together with the mentoring experience they accumulated, the graduate students who benefited from the co-op positions have positioned themselves as prime candidates for quality jobs as government employees. Graduate students were also given the opportunity to present the results of the work of the partnership at national aviation conferences.

Conclusion

This article presented a successful integration of government and academic organizations established to improve abilities in the testing and evaluation of air traffic decision support tools. These tools are crucial to the efficiency and safety of the national airspace system. The locations of these efforts ranged from the William J. Hughes Technical Center in Atlantic City, New Jersey, and to the FAA/Rowan Air Transportation Research Laboratory in Glassboro, New Jersey. Furthermore, two jointly developed visualization tools were presented, which were used during the post-RFR ERAM study, detailing the accuracy of ERAM's trajectory predictor and strategic conflict probe. TrajectoryGUI and FlightGUI proved to be helpful to the T&E analysts performing the study. Also, TrajectoryGUI and FlightGUI have been used by CPAT in support of other research activities (Paglione et al. 2006a, 2008b).

Partnering with academia proved to be less expensive than partnering with industry and offered more flexibility in collaborating, and at the same time

improved the FAA's T&E capabilities during the ERAM RFR analyses. The award-winning collaboration has gained positive exposure, produced advances in FAA's T&E processes, and has offered students experiences and opportunities in the real world. □

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